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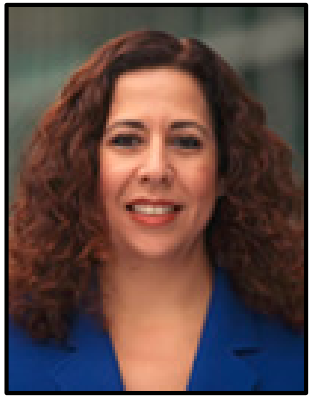
Munitions Mobility and Burial in Underwater Environments

September 24, 2020

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions



Rula A. Deeb, Ph.D.
Webinar Coordinator

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Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. David Bradley, SERDP and ESTCP
- **Understanding the Role of Munitions Mobility and Burial in Long-Term Management of Underwater UXO Sites** (55 minutes + Q&A)
  Dr. Joe Calantoni, U.S. Naval Research Laboratory
- **Final Q&A session**

Zoom Instructions

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- If you cannot download Zoom, you can view the slides using an internet browser
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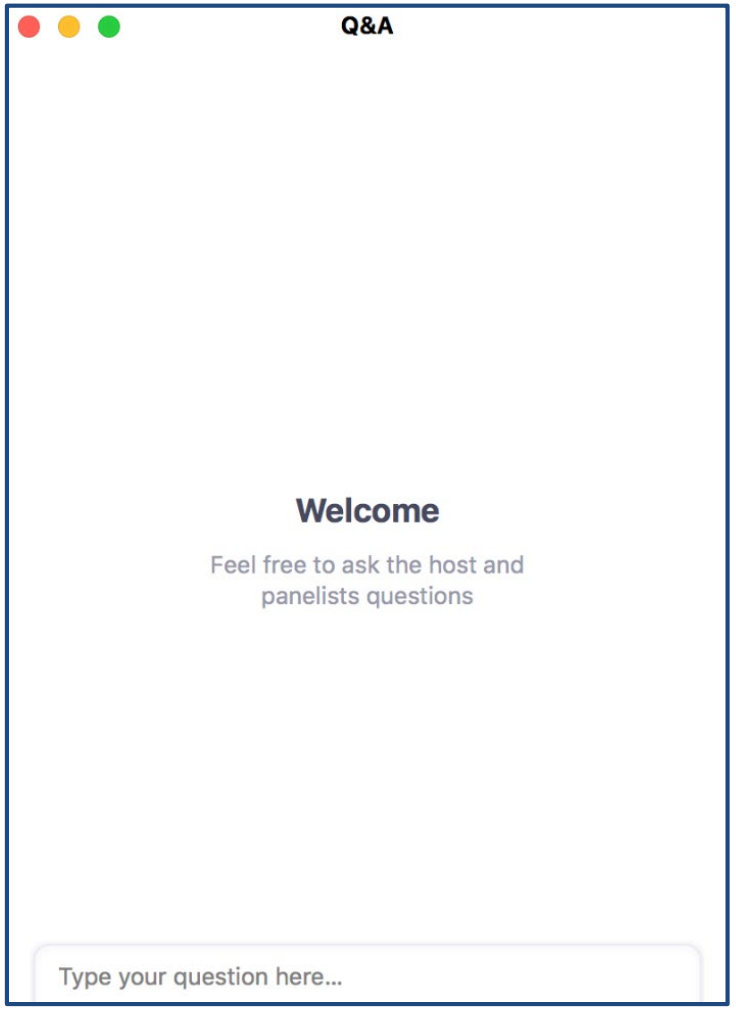
How to Ask Questions

- Find the Q&A button on your control bar and type in your question(s)
- Make sure to add your organization name at the end of your question so that we can identify you during the Q&A sessions



SERDP and ESTCP Overview

David L. Bradley, Ph.D.
SERDP and ESTCP

SERDP DOD • EPA • DOE | ESTCP

SERDP

- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

- Environmental Restoration
- Installation Energy and Water
- Munitions Response
- Resource Conservation and Resiliency
- Weapons Systems and Platforms

Munitions Response

- Munitions on land
  - Classification
- Munitions underwater
  - Wide area and detailed surveys
  - Cost-effective recovery and disposal
  - Characteristics of munitions underwater, their environment and mobility

SERDP and ESTCP Webinar Series

Date	Topic
October 8, 2020	Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available Fluorine-Free Foams (**Part 1**)
October 22, 2020	Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available Fluorine-Free Foams (**Part 2**)
November 5, 2020	Pathways under Non-Stationary Conditions and Their Implications for Wildlife and Human Exposure on Department of Defense Lands
November 19, 2020	Abiotic Degradation of Chlorinated Solvents in Subsurface Environments
December 10, 2020	Approaches for Managing Contaminated Sediments

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

Save the Date

SERDP • ESTCP
SYMPOSIUM

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

December 1-3, 2020

Registration for the virtual event is open!

Understanding the Role of Munitions Mobility and Burial in Long-Term Management of Underwater UXO Sites

Joe Calantoni, Ph.D.
U.S. Naval Research Laboratory

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Agenda

- Summary of existing knowledge, observations, and technologies
  - Do unexploded ordnance (UXO) wash up on the beach?
  - Technical approach
  - Mobility versus burial observations, technologies
- Q&A Session 1
- Designing demonstrations for modeling technologies
  - Environmental characterization
  - Deploy smart surrogate UXO
  - Setup and run prediction model(s) for mobility and burial
  - Predict and maintain infrastructure over multiple seasons and/or years
  - Scoring and evaluation?
- Q&A Session 2

MR19-1317 Project Team

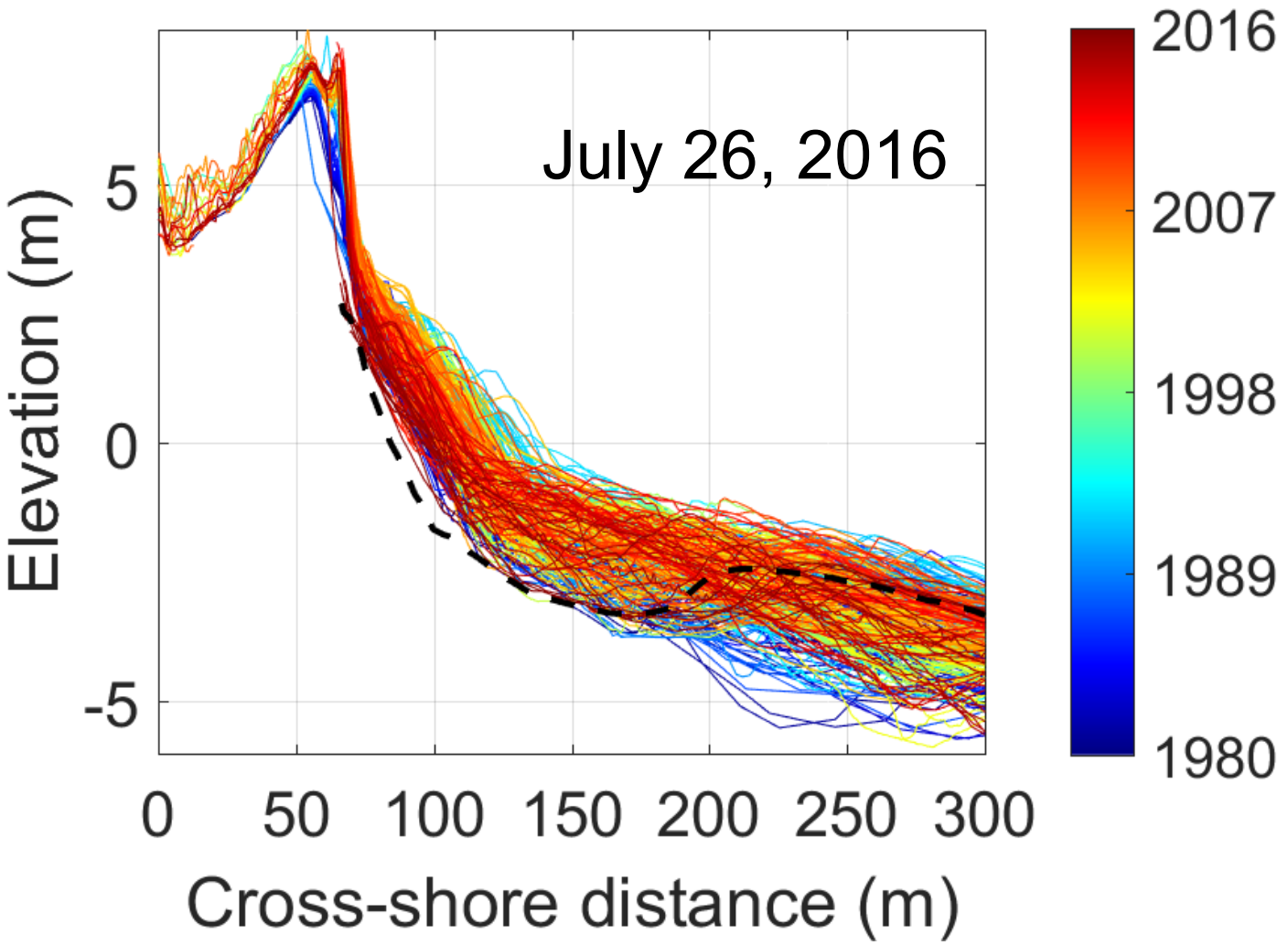
- Dr. Joe Calantoni (PI)
  - Sediment dynamics
- Mr. Ed Braithwaite (co-PI)
  - Seabed engineering
- Dr. Alex Sheremet (co-PI)
  - Water waves mechanics
- Dr. Haki Klammler and Dr. Scott Wasman
  - Geotechnical engineering
- Mr. Chuck Key, Mr. Sam Griffith and Dr. Carter DuVal
  - Engineering, geology, signal processing

Do UXO Wash up on the Beach?

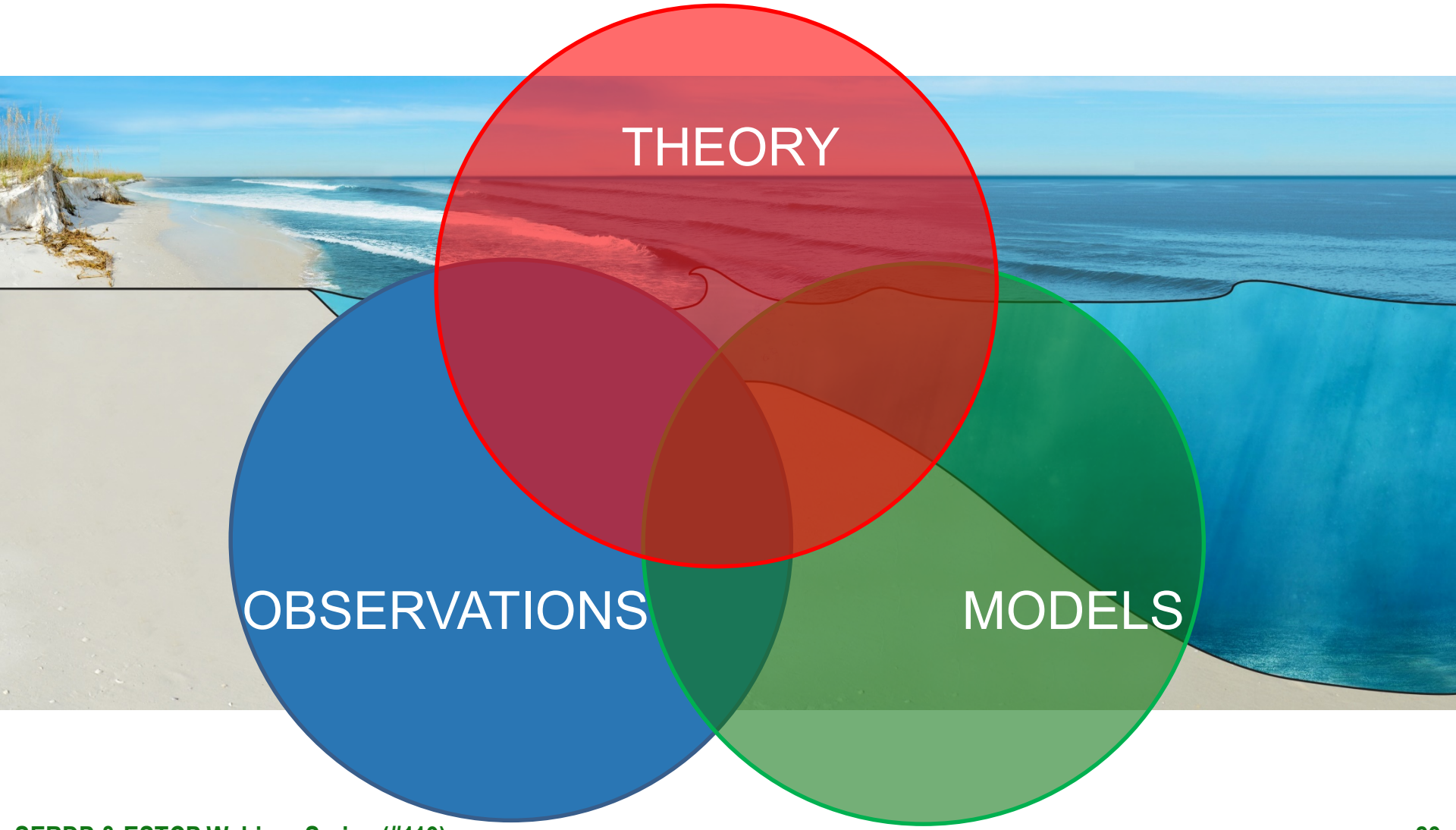
24-28 July 2016 at Duck, NC

UXO appeared on the beach

Do UXO Wash up on the Beach?

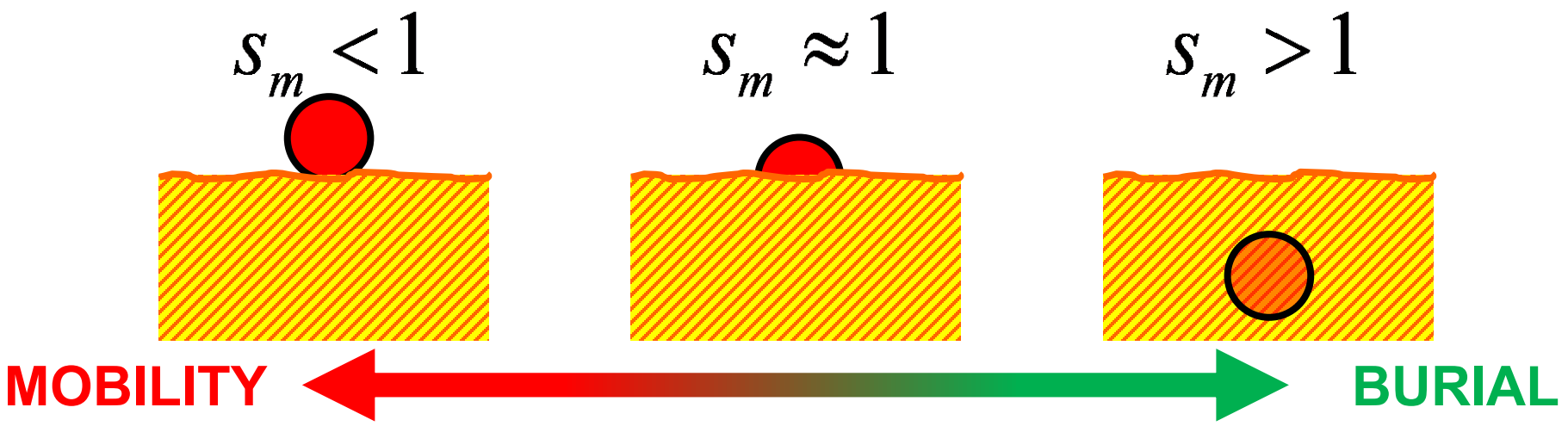


Technical Approach



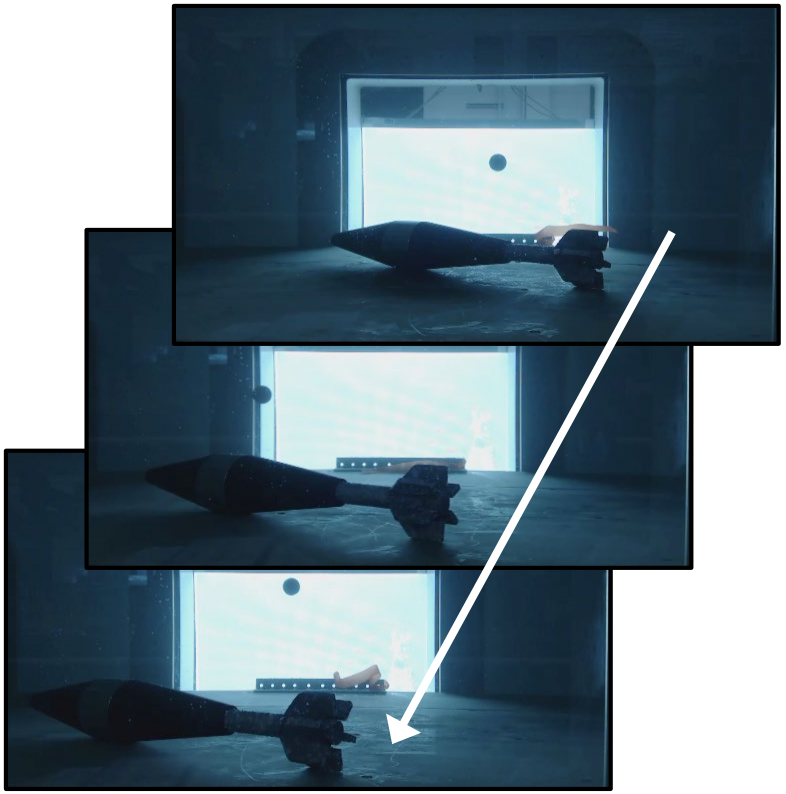
Mobility versus Burial Hypothesis

s_m = non-dimensional density of the munitions

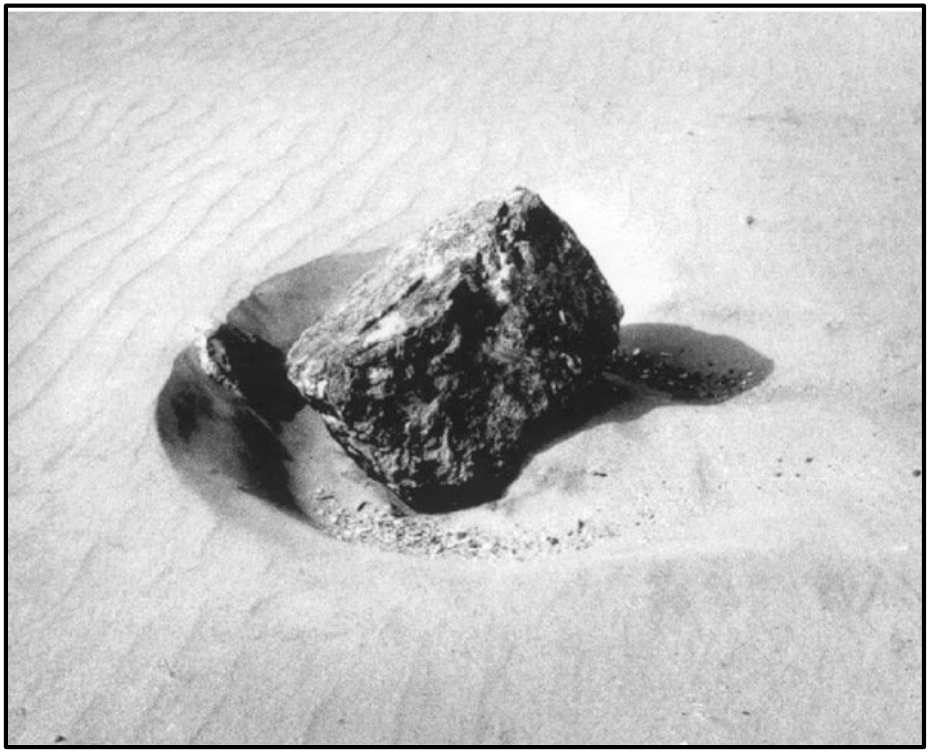


Mobility versus Burial Observations

Initial Mobility



Scour Burial

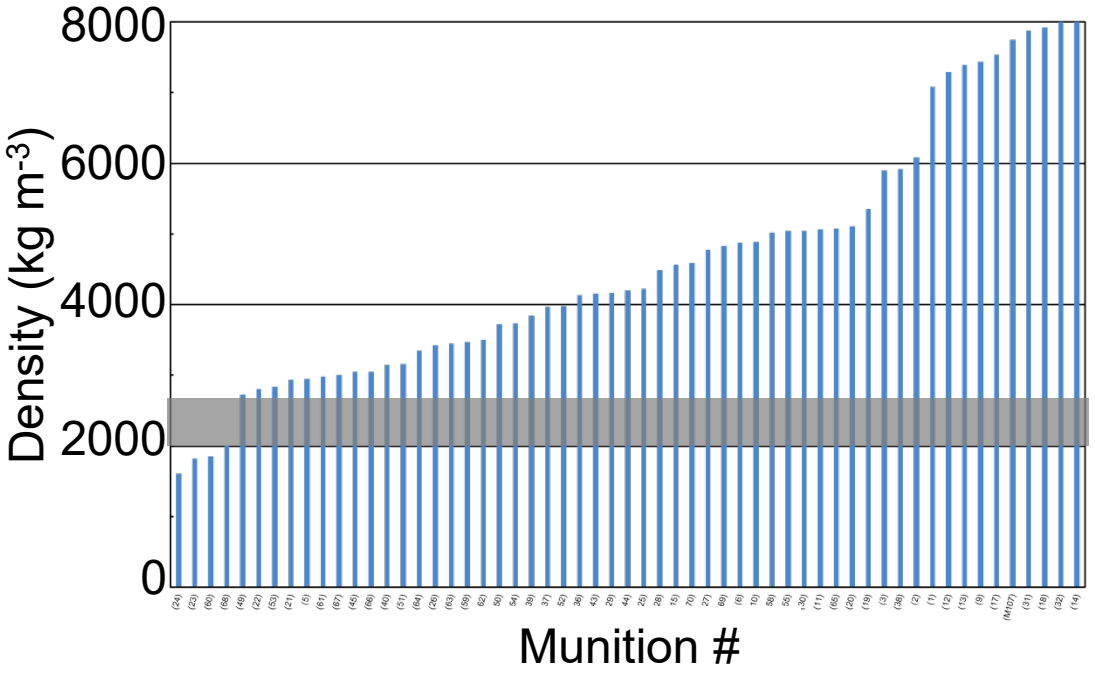


Sources: MR-2410; Inman & Jenkins, *Encyclopedia of Coastal Science*, 2005

Density of Munitions

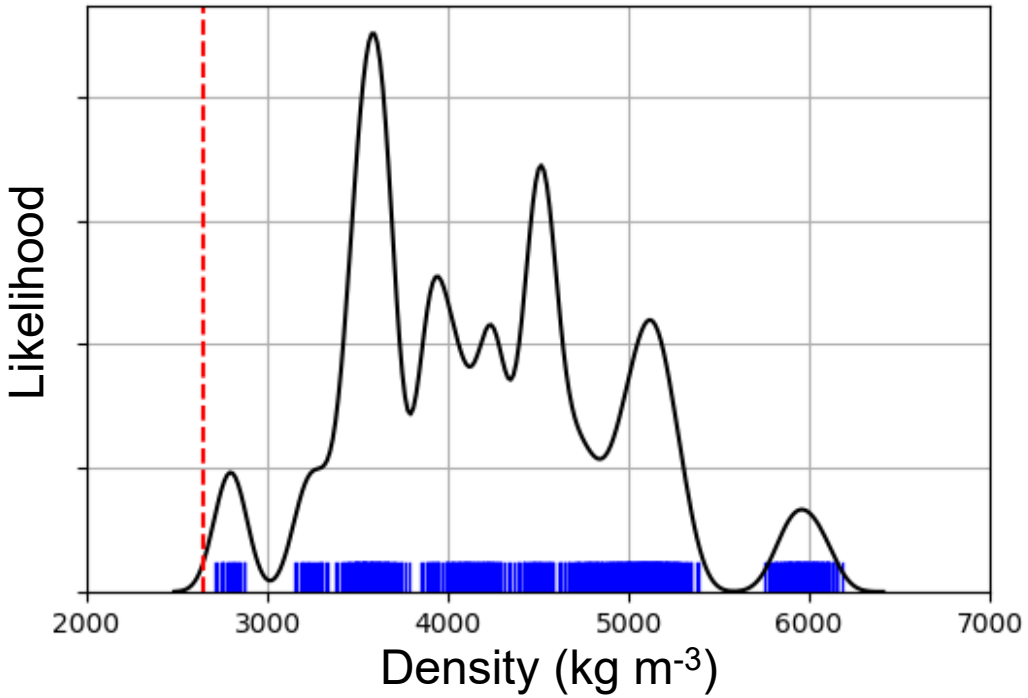
Munitions want to bury!

- Measured 70 items
  - Range: inert certified to simple surrogates
- Built CAD models
- $s_m \geq 1$ for 95% of items



Note: CAD = computer-aided design

Density of Munitions



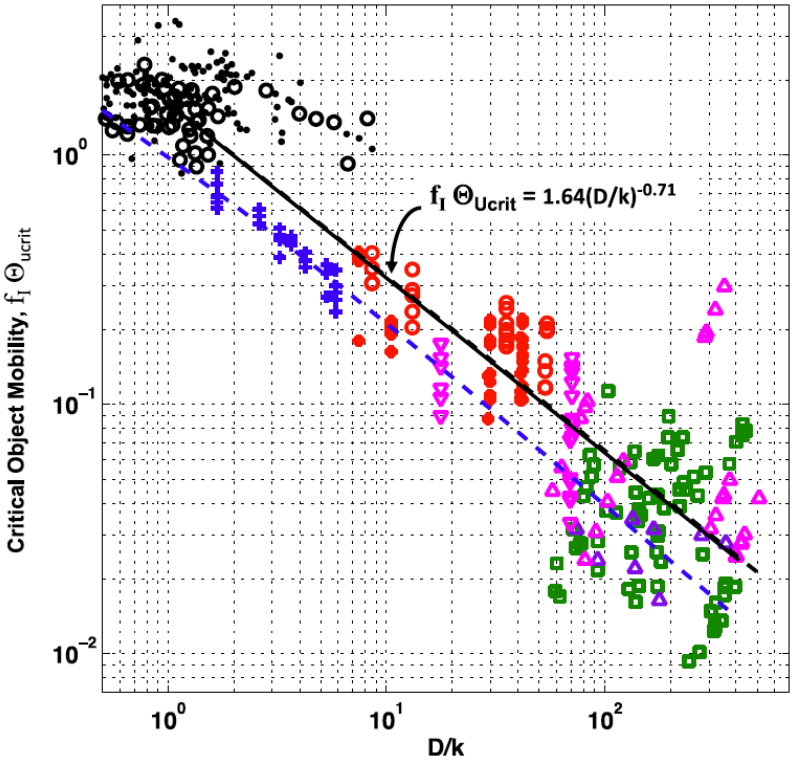
Overall likelihood distribution, all 155 mm caliber

Kernel density estimate of likelihoods
Combination of munition "weight options"
Density of sand, 2,650 kg m^{-3}

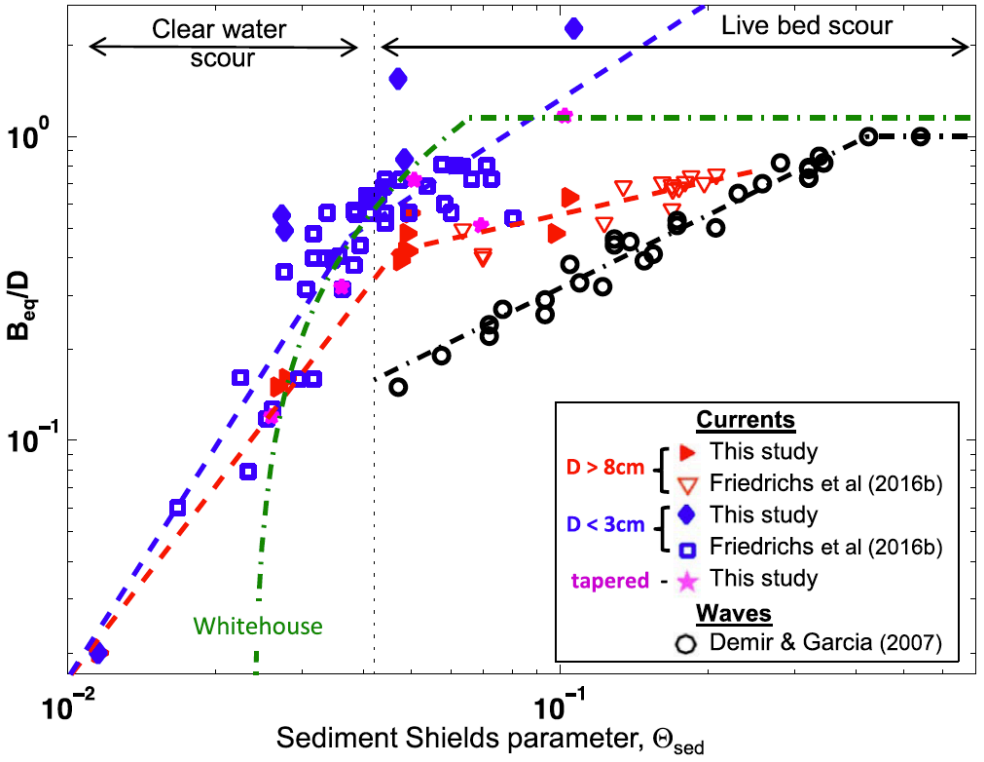
- Estimated density distribution for each entry in Army technical manual
- Distributions for entries from a single caliber combined into an overall likelihood distribution
  - Likelihood = prior probability of a munition having a certain density

Mobility versus Burial Observations

Initial Mobility



Scour Burial



Empirical knowledge compiled for mobility and burial

Source: Rennie, Brandt, and Friedrichs, *Ocean Engineering*, 2017

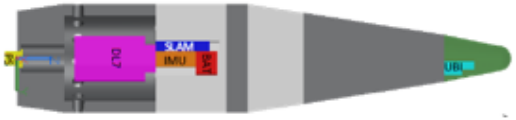
Mobility versus Burial Technologies

Mobility versus Burial Technologies

Hydra-70 rocket

mass: 4.06 kg; density: 3,320 kg/m^3

155 mm HE

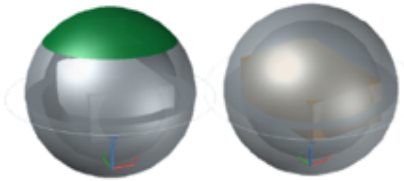


mass: 41.29 kg; density: 4,230 kg/m^3

81 mm mortar

mass: 4.58 kg; density: 4,180 kg/m^3

BLU61 cluster bomb



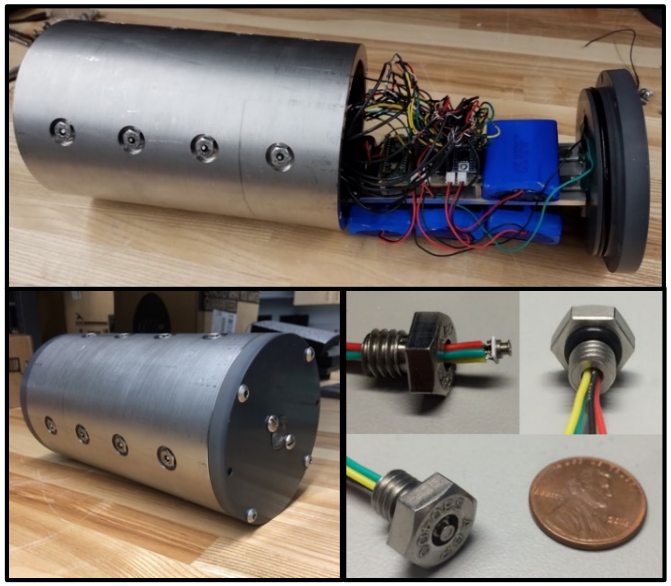
mass: 1.4 kg; density: 4,760 kg/m^3

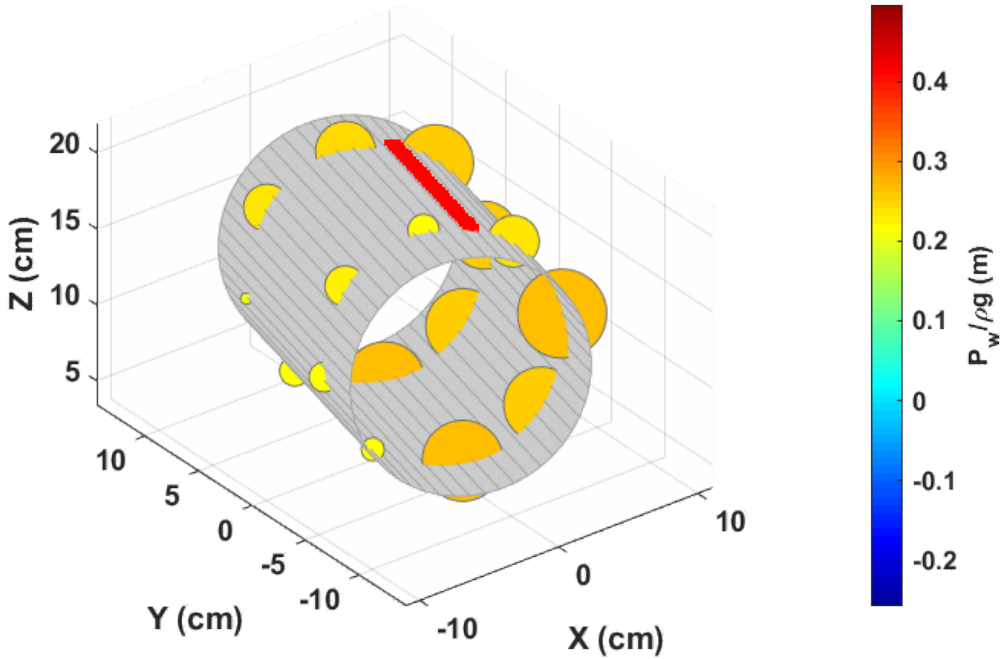
Source: MR-2503

Mobility versus Burial Technologies

Pressure Mapping on UXO

- 16 pressure sensors
- 9 DOF IMU
- 3-day endurance





Note: DOF IMU = degrees of freedom inertial measurement unit ***Source***: MR-2731

Mobility versus Burial Observations

Observed Burial at Fort Foster, ME

- Timing and rate of burial was directly observed
- Confirmed by photographs during daylight hours

Source: MR-2731

Mobility versus Burial Technologies

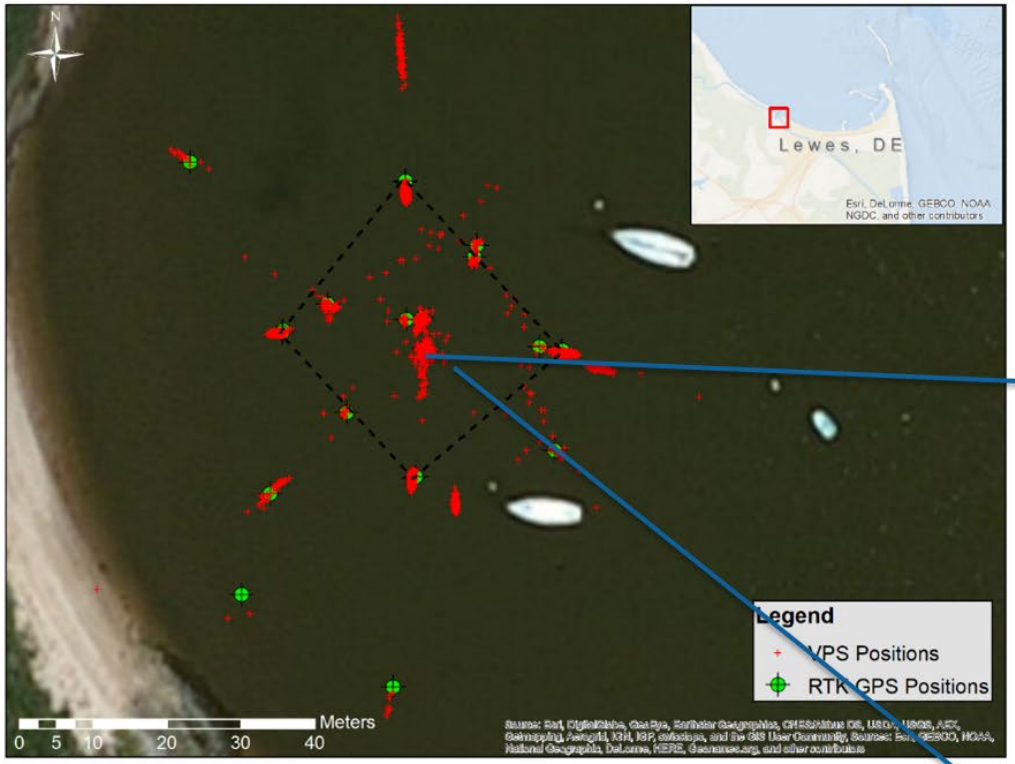
Vemco Positioning System

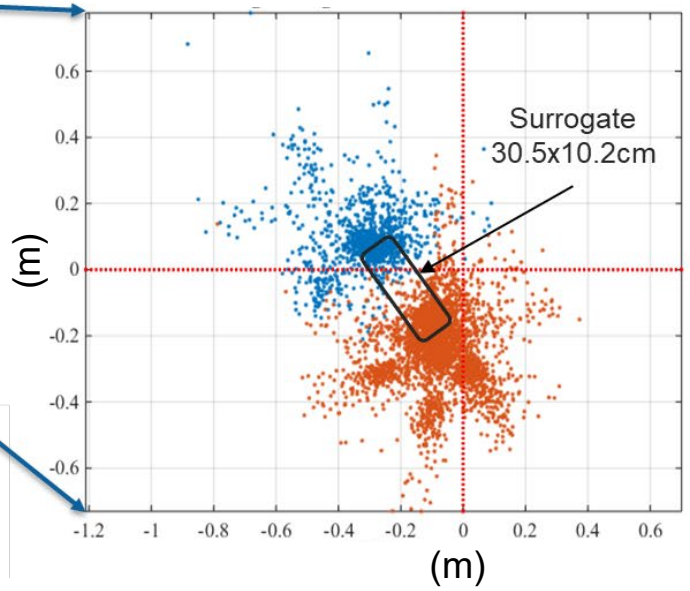
- Acoustic tracking system (180kHz)
- 10 cm positional accuracies
- Long endurance

Source: MR-2730

Mobility versus Burial Technologies

Vemco Positioning System

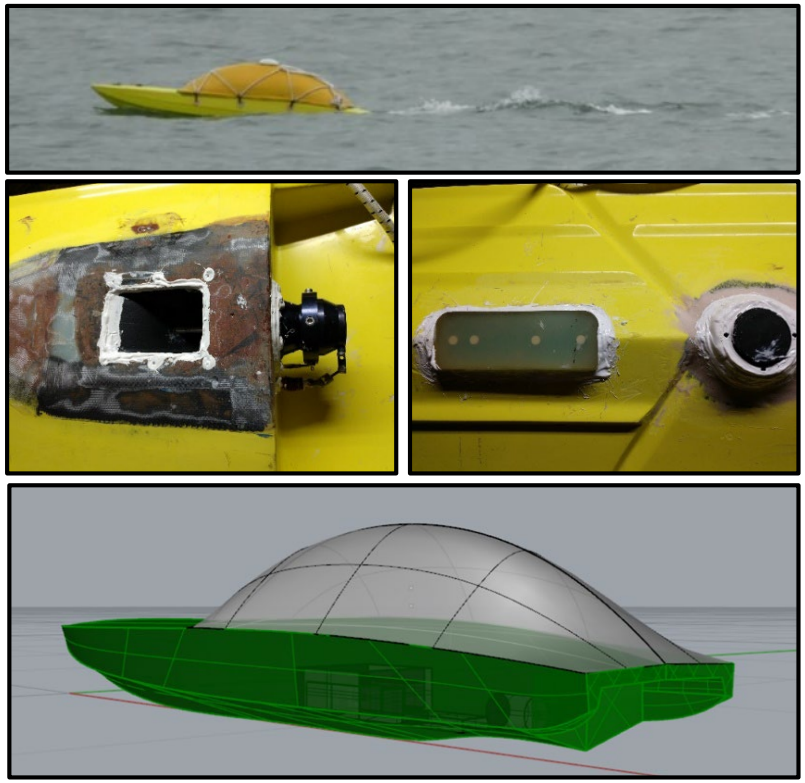




Source: MR-2730

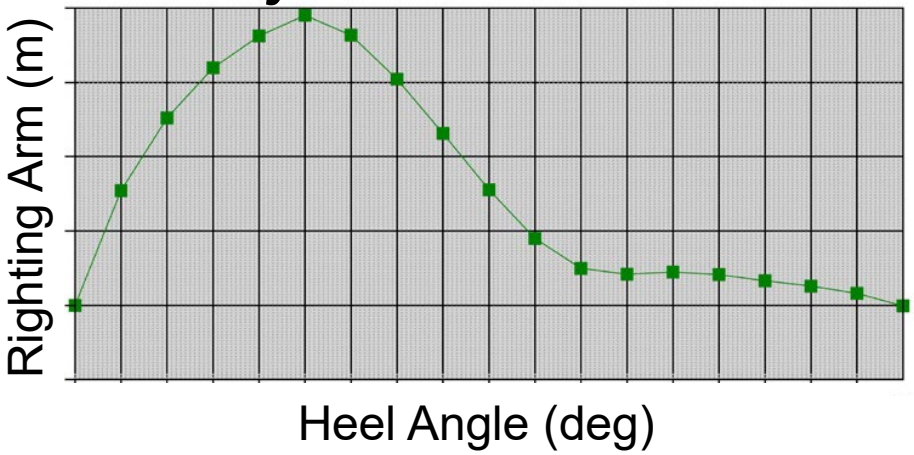
Mobility versus Burial Technologies

Surf-Zone Capable Autonomous Surface Vessel



- Jet drive
- USBL acoustic array and single beam echo sounder
- CAD model for self-righting flotation lid

Stability curve from CAD model

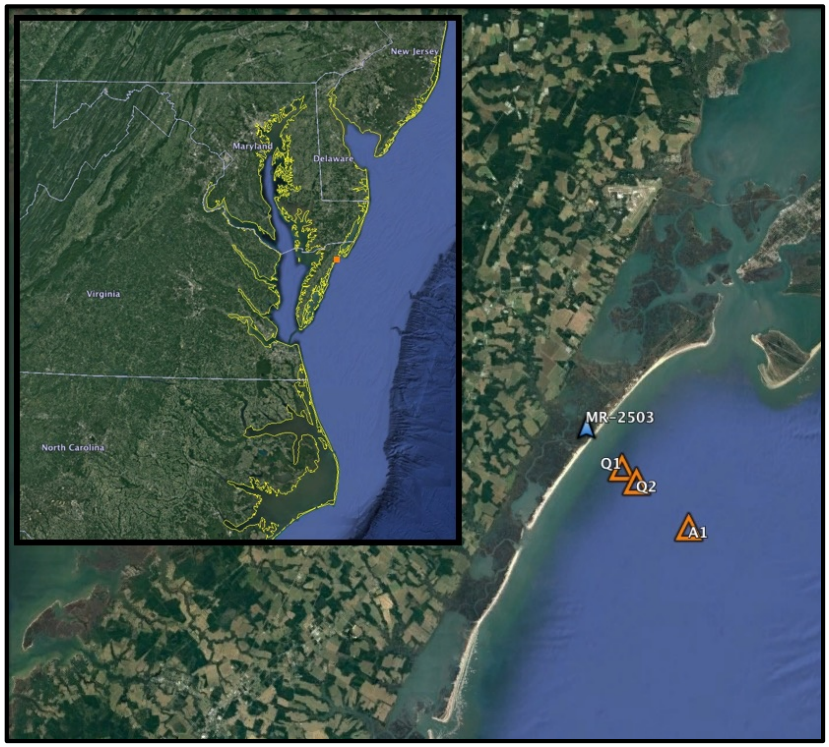


Note: USBL = ultra-short baseline ***Source***: MR-2729

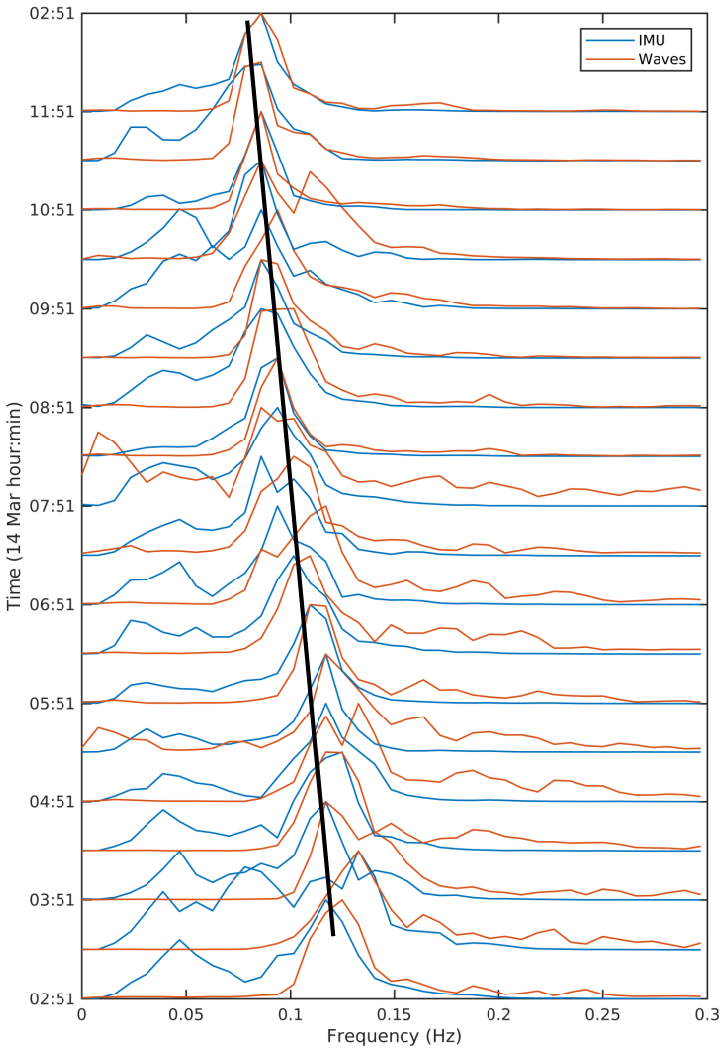
Mobility versus Burial Observations

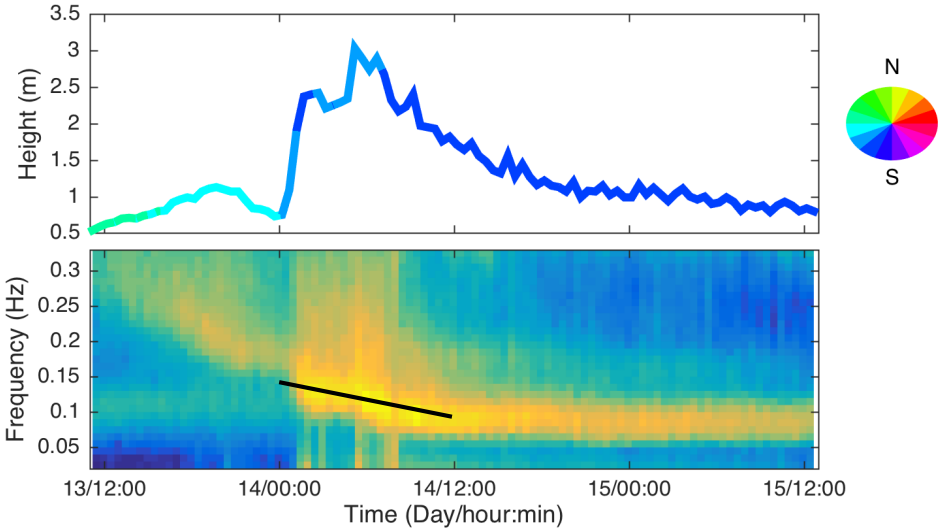
Wallops Island Munitions Mobility Experiment

- Storm event on 14 Mar 2017
- 81 mm smart munition with IMU
  - 16 Hz; 9-m depth
- Integration interval is 9.9 hours
  - Total of 570,240 points
- IMU integrated displacement
  - 62.9 m with 344 deg heading
- Diver measured displacement
  - 61.6 m with 340 deg heading



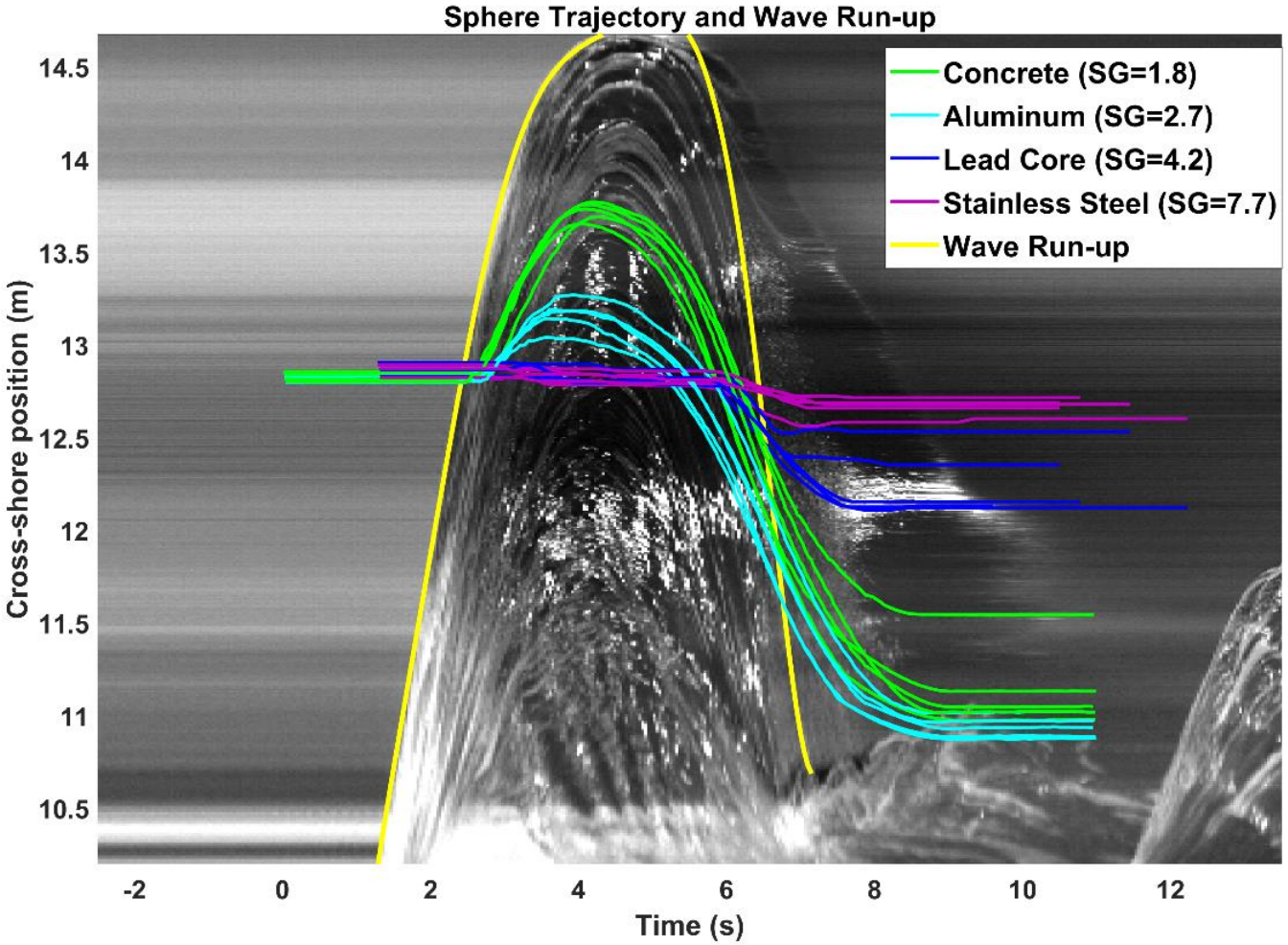
Mobility versus Burial Observations





- Munition rolling frequency was consistent with the peak wave frequency during the storm

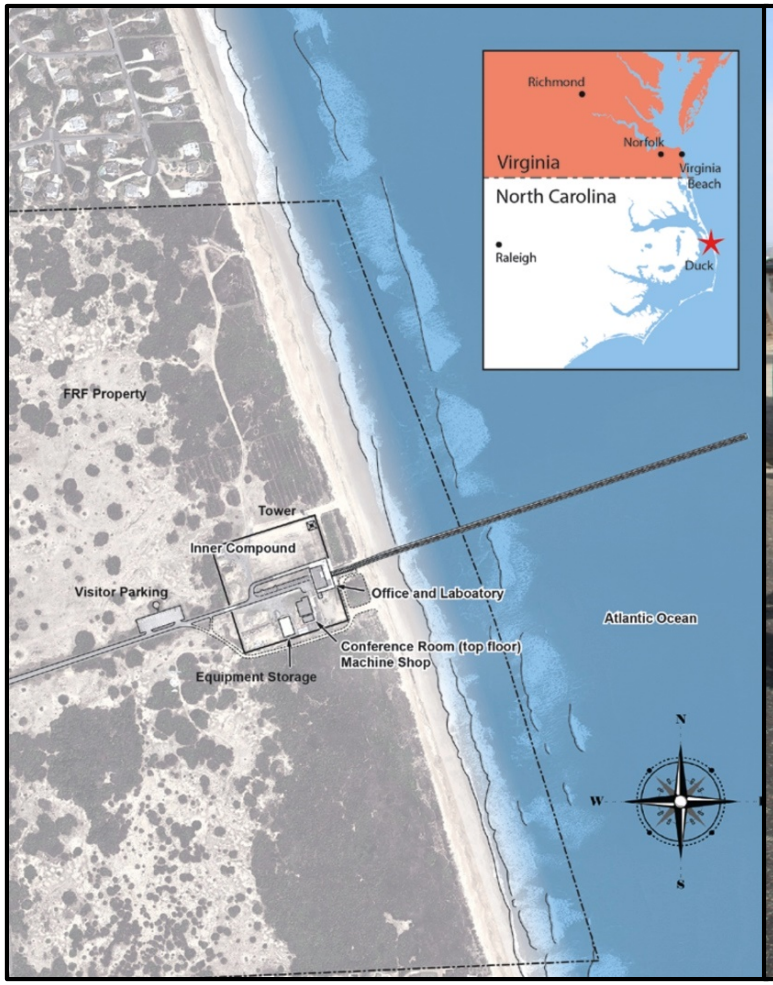
Mobility versus Burial Observations



- Mobility in the swash zone
- Motion governed by bulk density
- Less dense spheres move onshore first and then far offshore
- More dense spheres do not move onshore

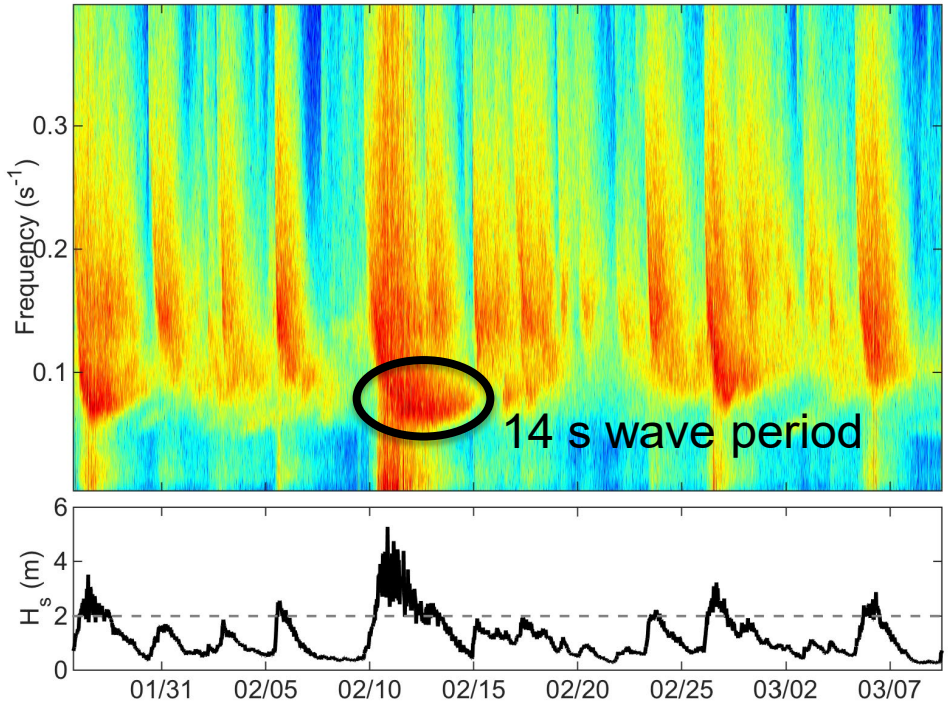
Note: SG = specific gravity; ***Source***: MR-2503

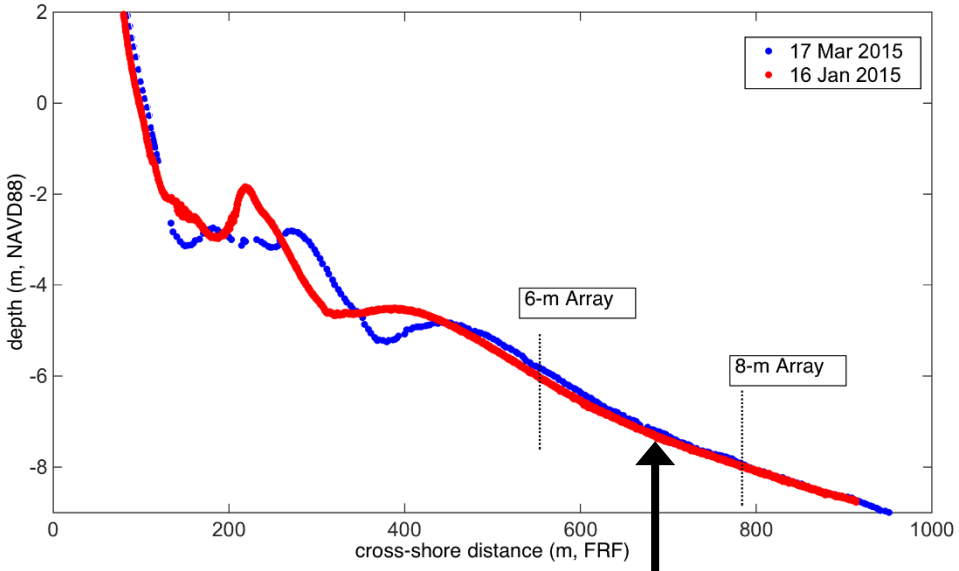
Mobility versus Burial Observations



Mobility versus Burial Observations

January - March 2015, Duck, NC

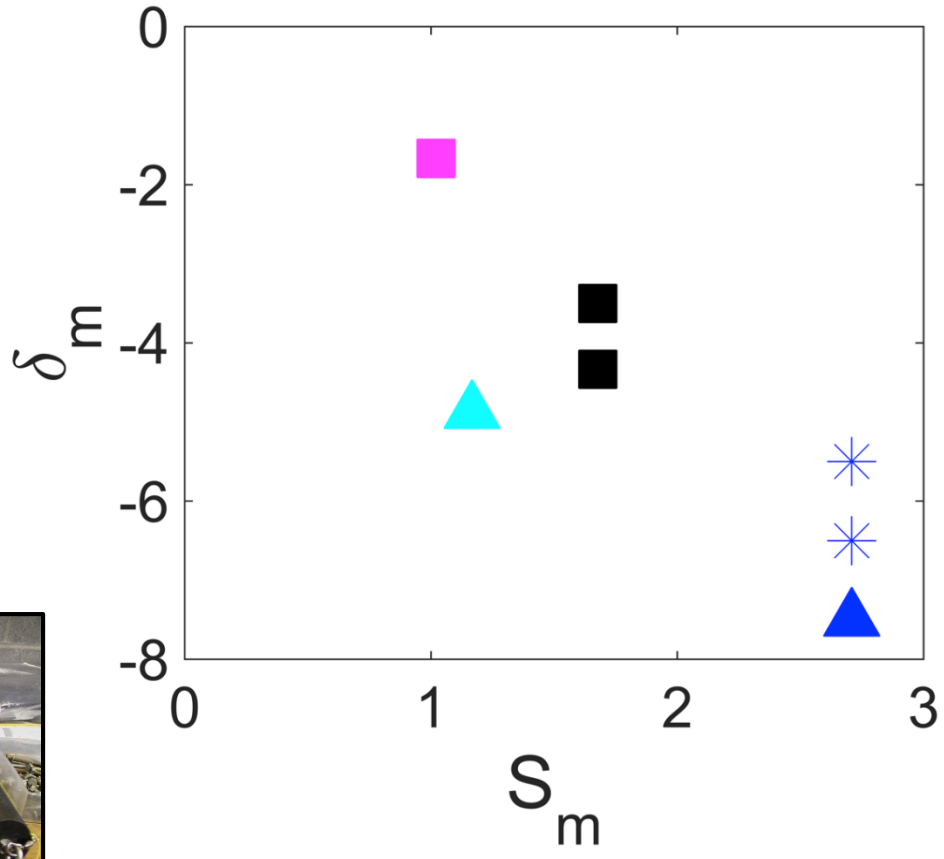




Over prior 35 years seafloor varied by +/- 30 cm (NAVD88 datum)

Mobility versus Burial Observations

- Extreme burial (~60 cm) at Duck, NC
- Burial estimates from diver observations
- 3 calibers
  - 155 mm, 81 mm, 25 mm

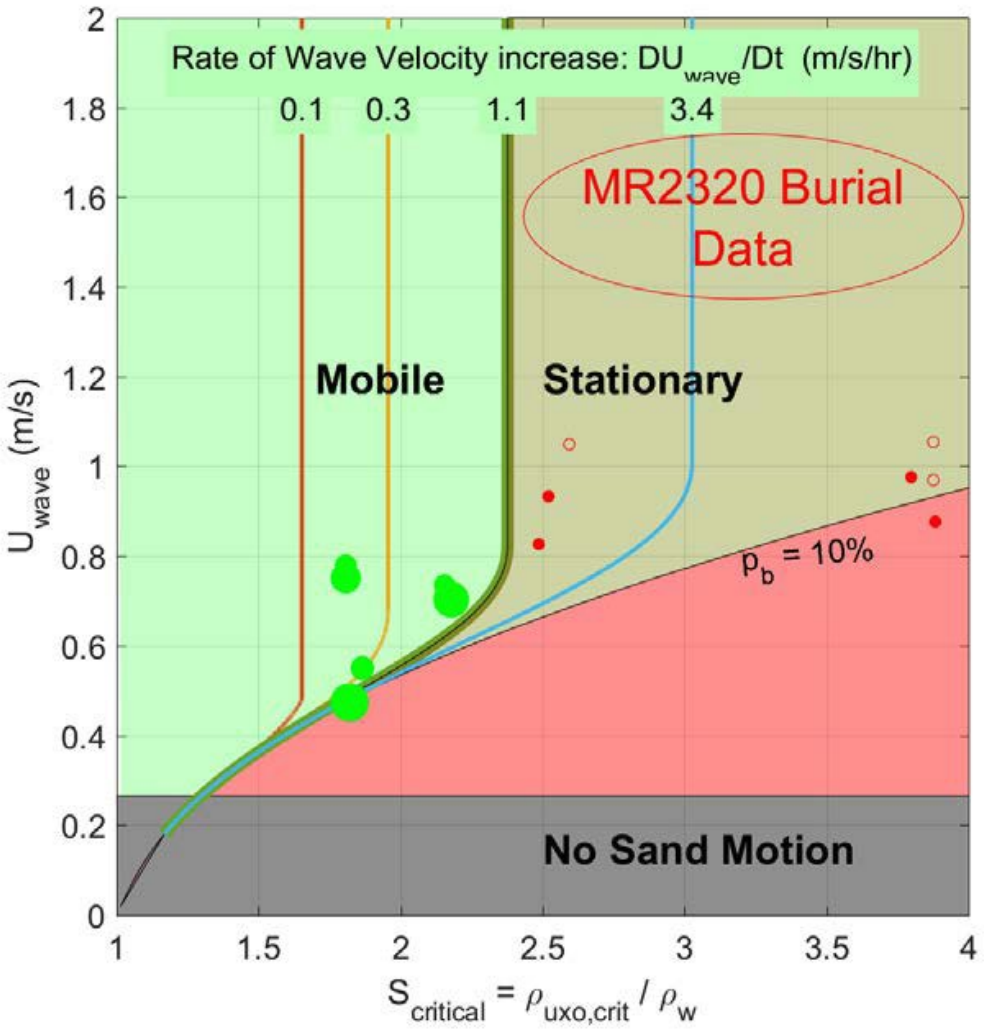


Density and caliber are the most important characteristics

Mobility versus Burial Diagram

Wave Velocity versus UXO Density

- Includes different rates of wave velocity increase
- Wave velocity observed or estimated at the bed, U_{wave}
- Includes initial burial, p_b
- Bulk density is normalized by density of water, $S_{critical}$



Source: *Final Report*, MR-2319

Summary

- Bulk density is most significant parameter
- Wide range of field observations exist
- Technologies developed for instrumenting surrogate munitions
- Technologies developed for tracking surrogate munitions

Collectively developed a strong understanding of munitions phenomenology – work ongoing

Q&A Session 1

Agenda - Part II

Demonstrations for Modeling Technologies

- Perform environmental characterization
- Deploy smart surrogate UXO
- Setup and run prediction model(s) for mobility and burial
- Predict and maintain infrastructure over multiple seasons and/or years
- Scoring and evaluation

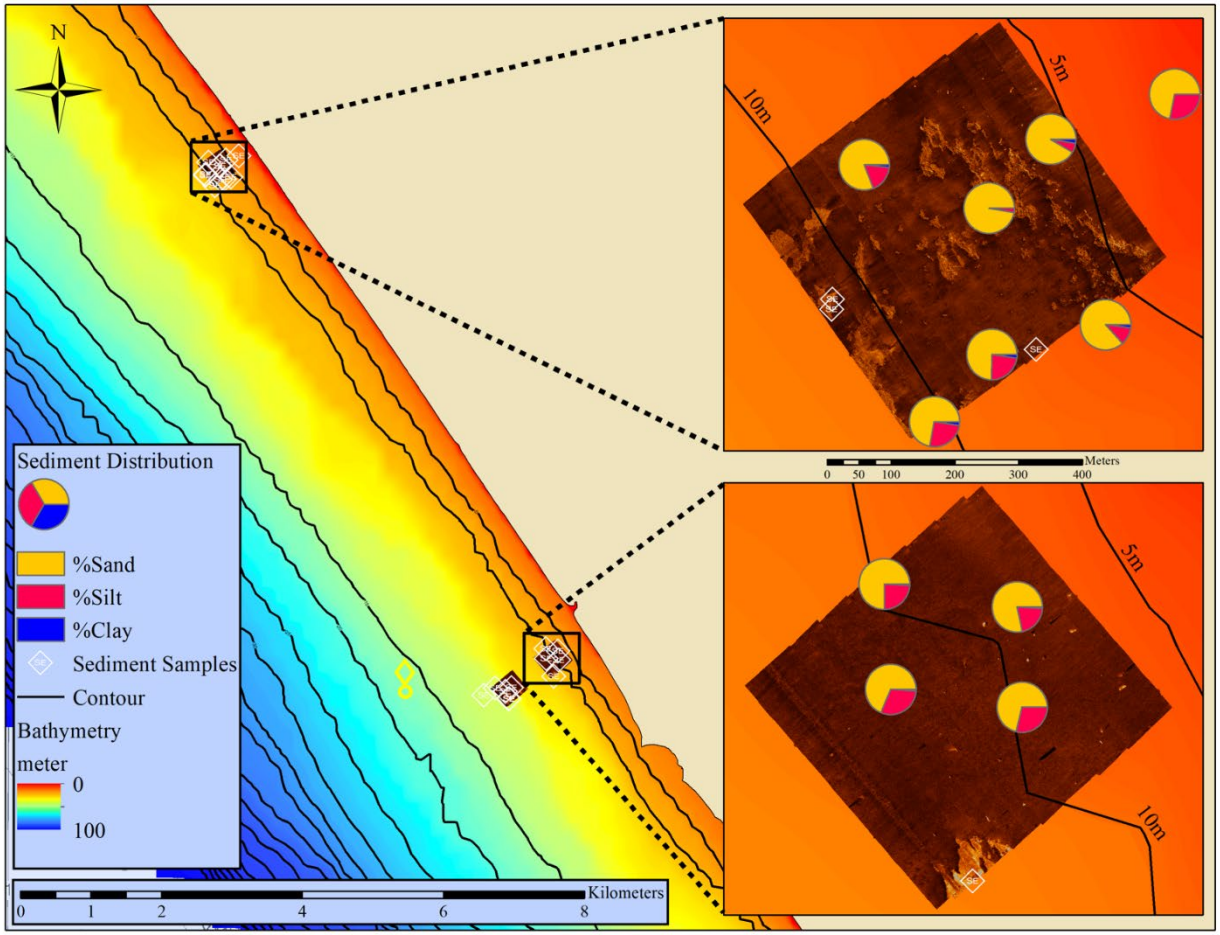
Problem Statement

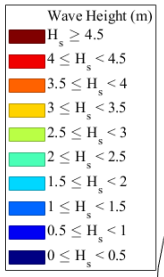
- How to demonstrate capability to predict munitions mobility and burial in underwater environments?
- Time scales and locations for demonstration
- Appropriate metrics for success?
  - Academic versus regulator
- Quantifying risk for long-term site management?
  - Tactical decision aids

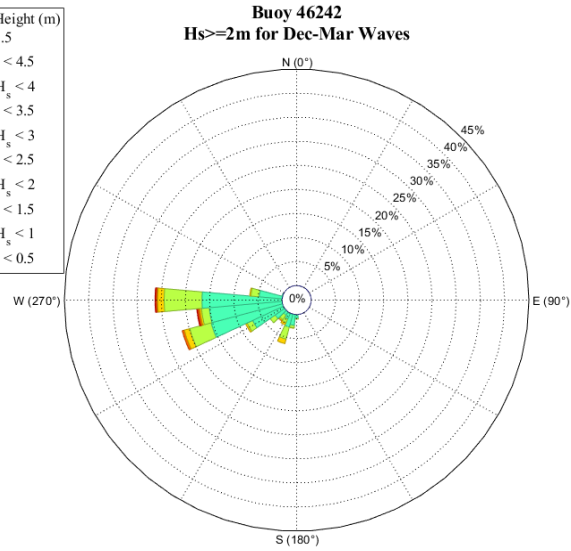
MR19-1317 Overview

- Towards developing demonstrations
- Research objectives
  - Reduce dimensionality of the problem for munitions
- Technical approach
  - Develop new geotechnical model for predicting burial
  - Novel surrogate munitions to validate model
- Long-term goal
  - Develop guidelines for future demonstrations

Environmental Characterization







- Public data sources for regional forcing
- Bathymetry
- Sedimentology
- Long-term monitoring of local conditions

Survey from 13-16 Jan 2020 at Camp Pendleton, CA

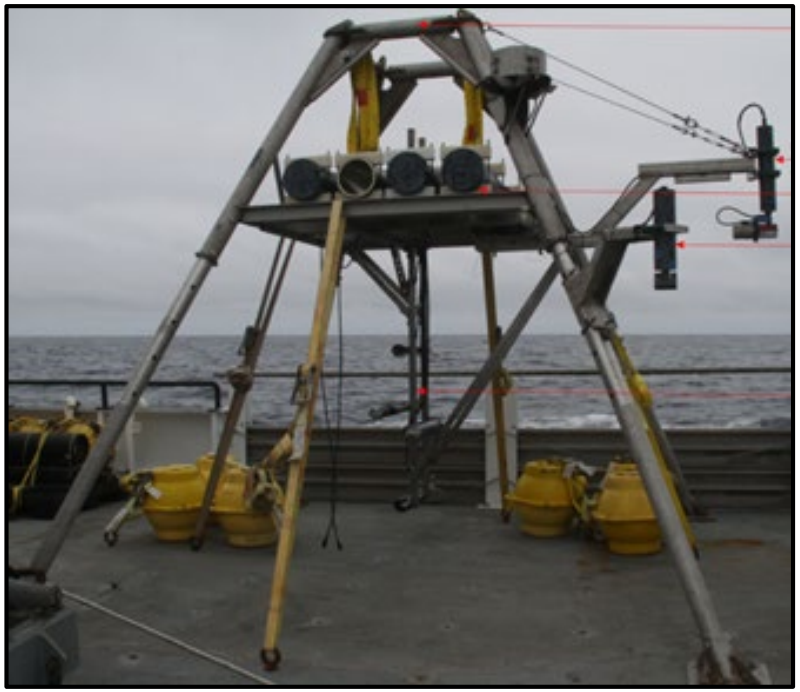
Environmental Characterization

Bottom moored ADCPs

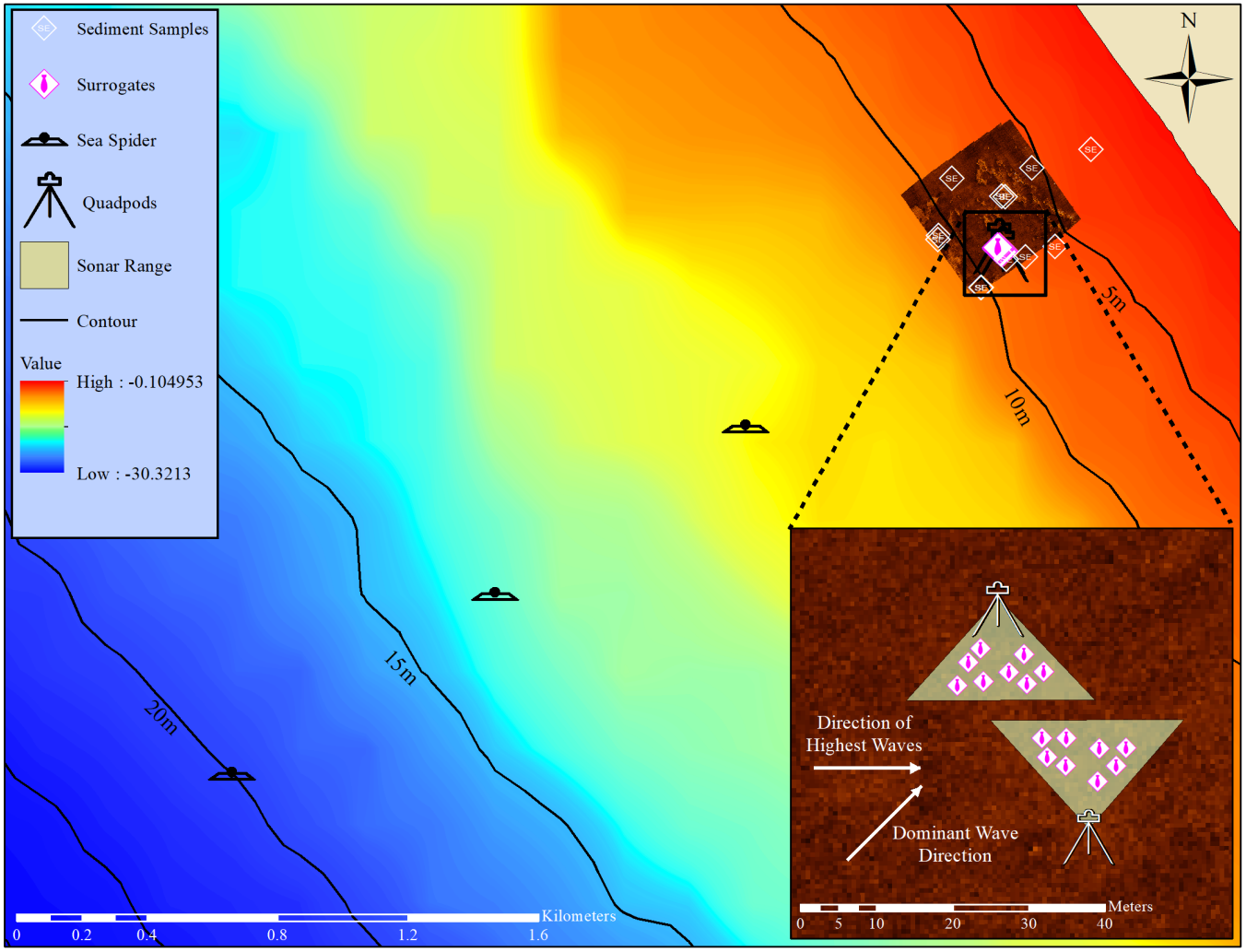
Far field waves and currents

Large platforms

Near field sonar images

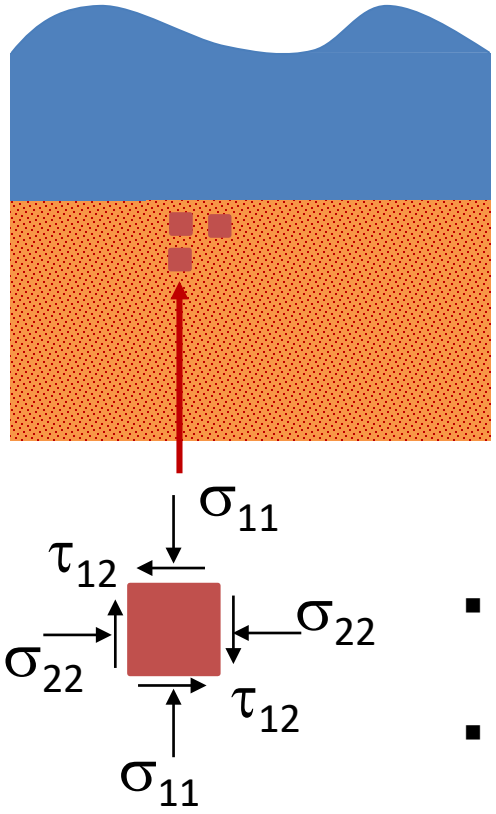


Environmental Characterization



Extreme Burial Technology

Measuring Seabed Pressures



pore pressure, **u**

total stress, σ_T

$\sigma_{11} = \sigma_T - \mathbf{u}$ (effective stress)

$\tau_{12} = \sigma_{11} \tan\phi$ (shear stress)

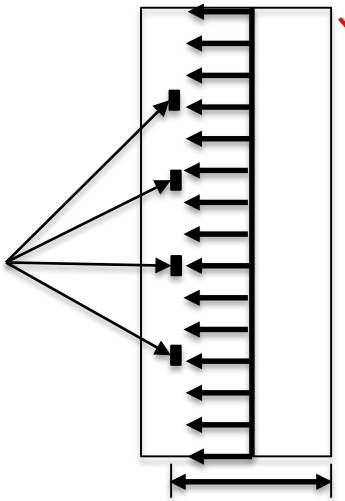
where ϕ = soil friction angle

- Increasing **u** → σ_{11} and $t_{12,}$ decrease, seabed approaches unstable state
- Measured σ_T and **u** provides temporal state of stress (stable versus unstable)
- Unstable seabed leads to munition burial, but how deep?

Extreme Burial Technology

Sensor Calibration

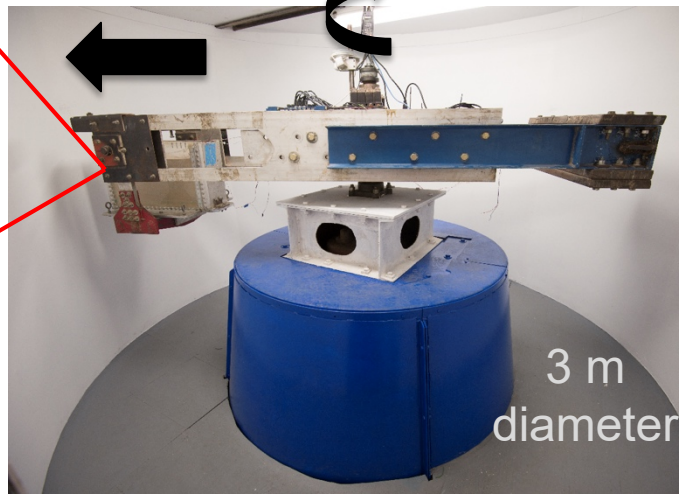
Sample container with sensors embedded in saturated sediment



~ 0.3m

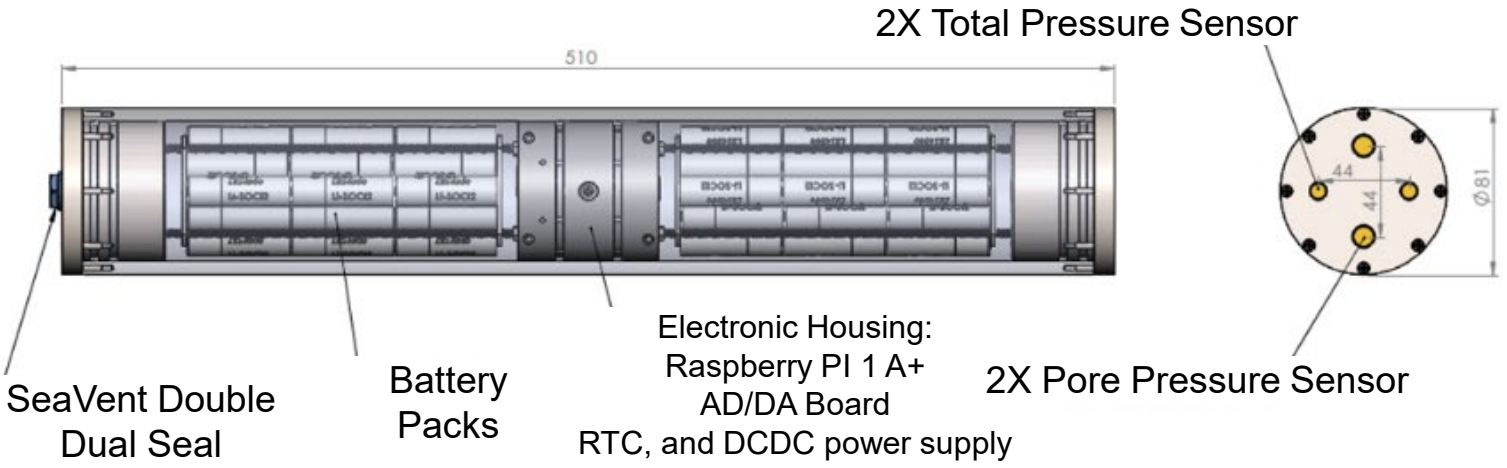
centrifugal force

centrifuge rotation



Extreme Burial Technology

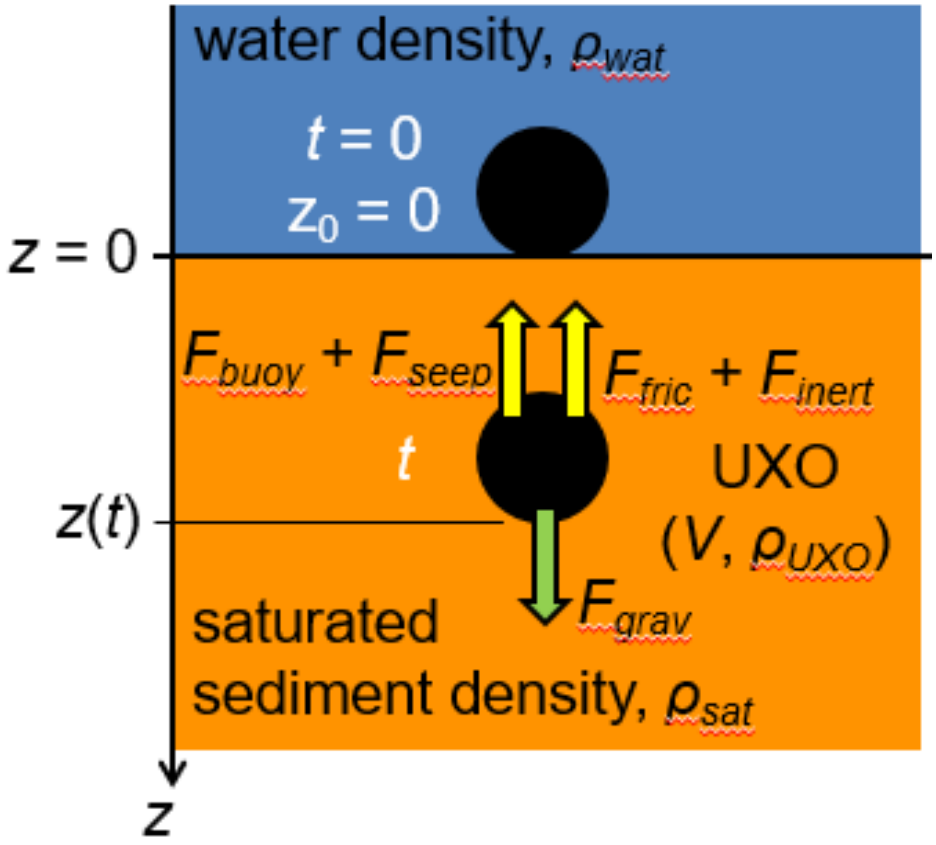
Simplified Smart Surrogate



Detailed Surrogate

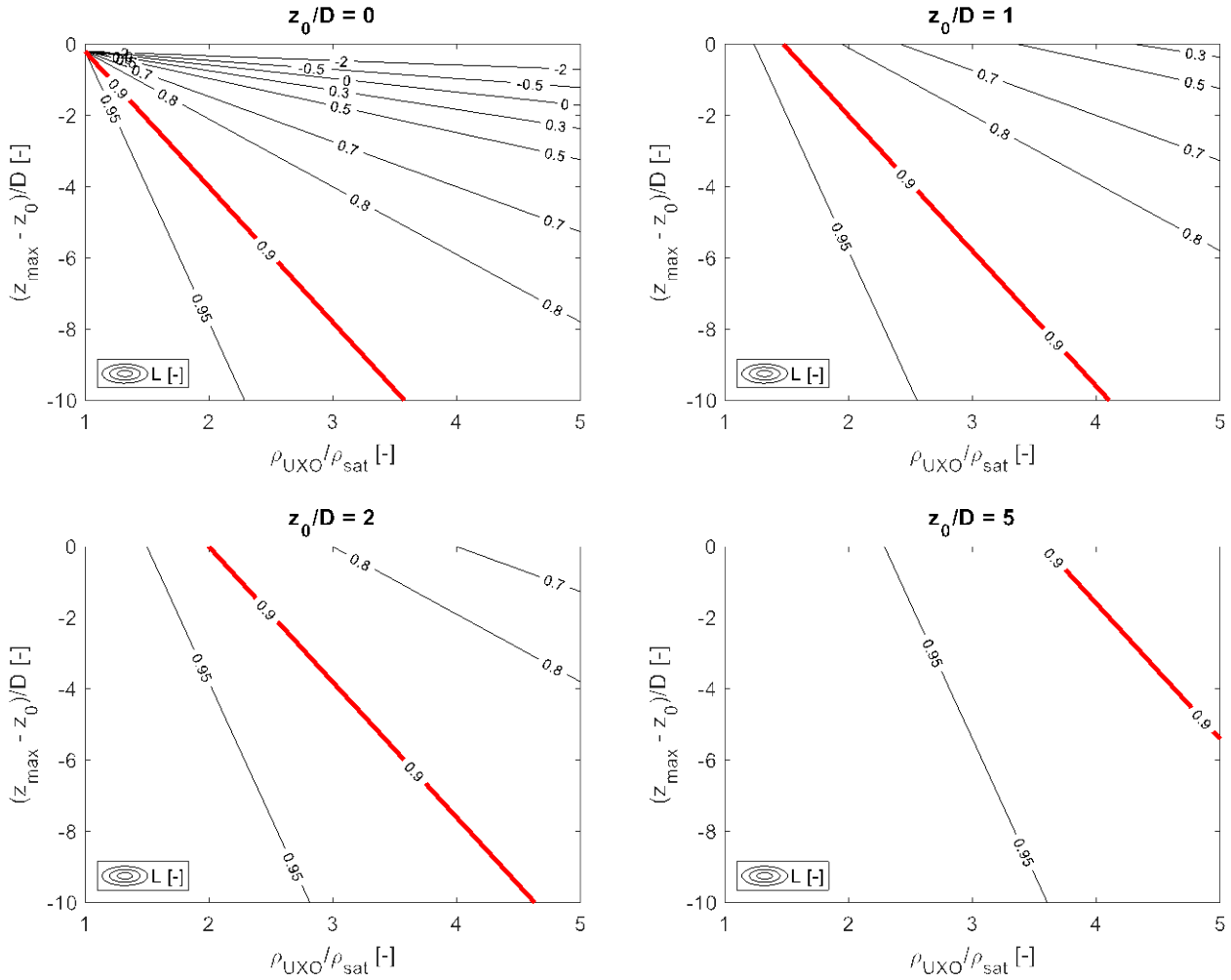
81 mm surrogates	In-Air Weight (kg)	Density (kg m^{-3})
Low	8.27	3,149
Medium	10.69	4,069
High	11.56	4,847

Dynamic Seabed Burial Model



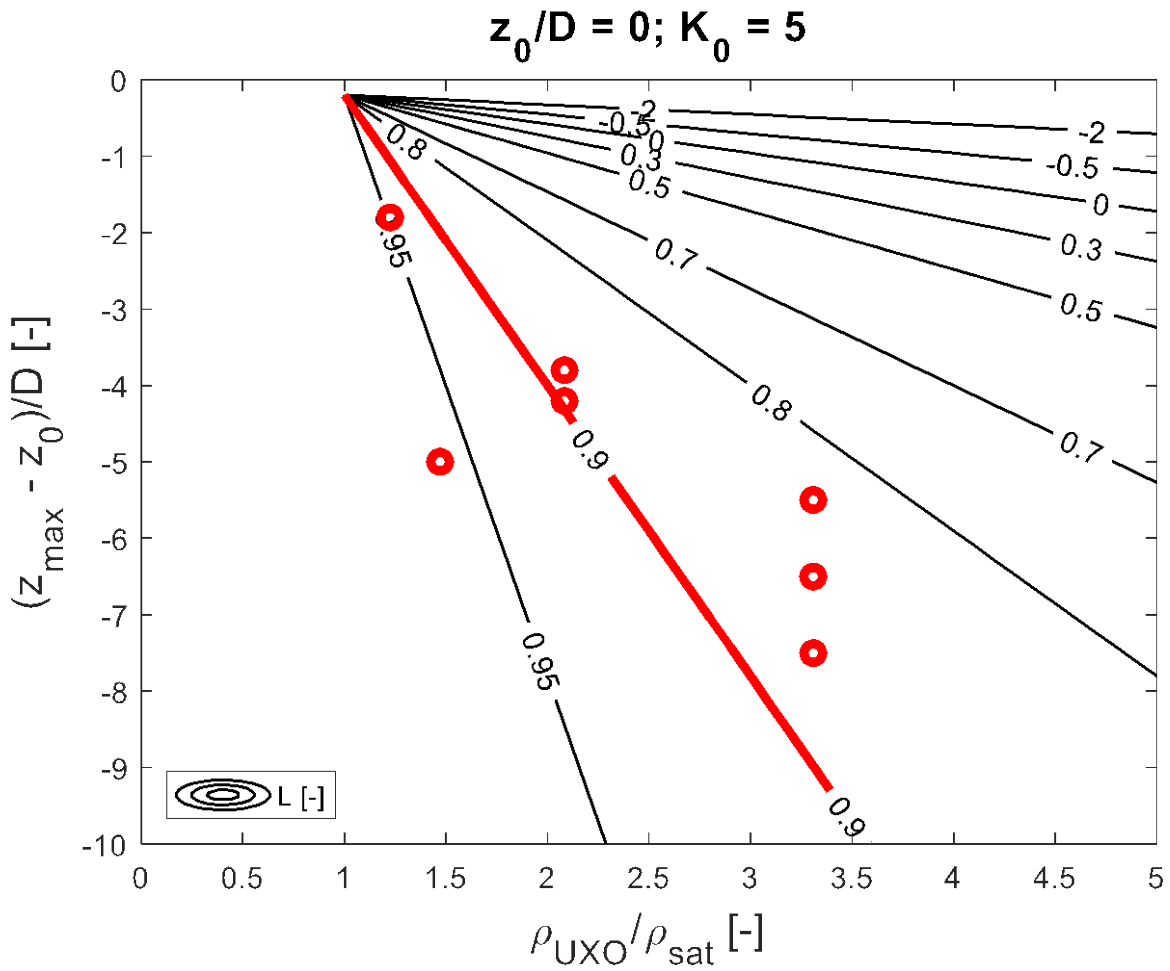
- Assume force balance on UXO
- Partition water-saturated sediment bed with distribution of pore pressure and effective stress
- Predict final burial depth
  - Linear function of density ratio

Dynamic Seabed Burial Model



- z_0 = initial object burial position
- Density based on saturated sediment
  - $\rho_{sat} \approx 2{,}000$ kg/m^3
- No depth dependence on the degree of liquefaction
- Model is calibrated (K_0) using Duck, NC data

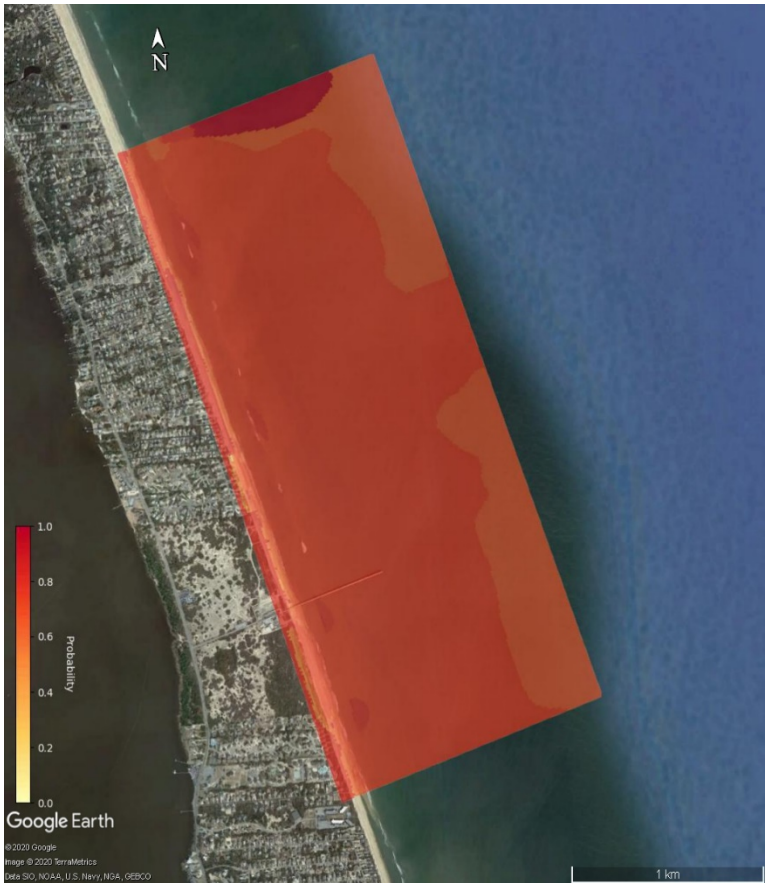
Dynamic Seabed Burial Model



- Dependence on calibration parameter, K_0
- Observed burial depths at Duck, NC (red circles)
- Contour lines of burial depth for different values of K_0
- Liquefaction degree, L, at Duck, NC (red line)

PEMS for Munitions Mobility

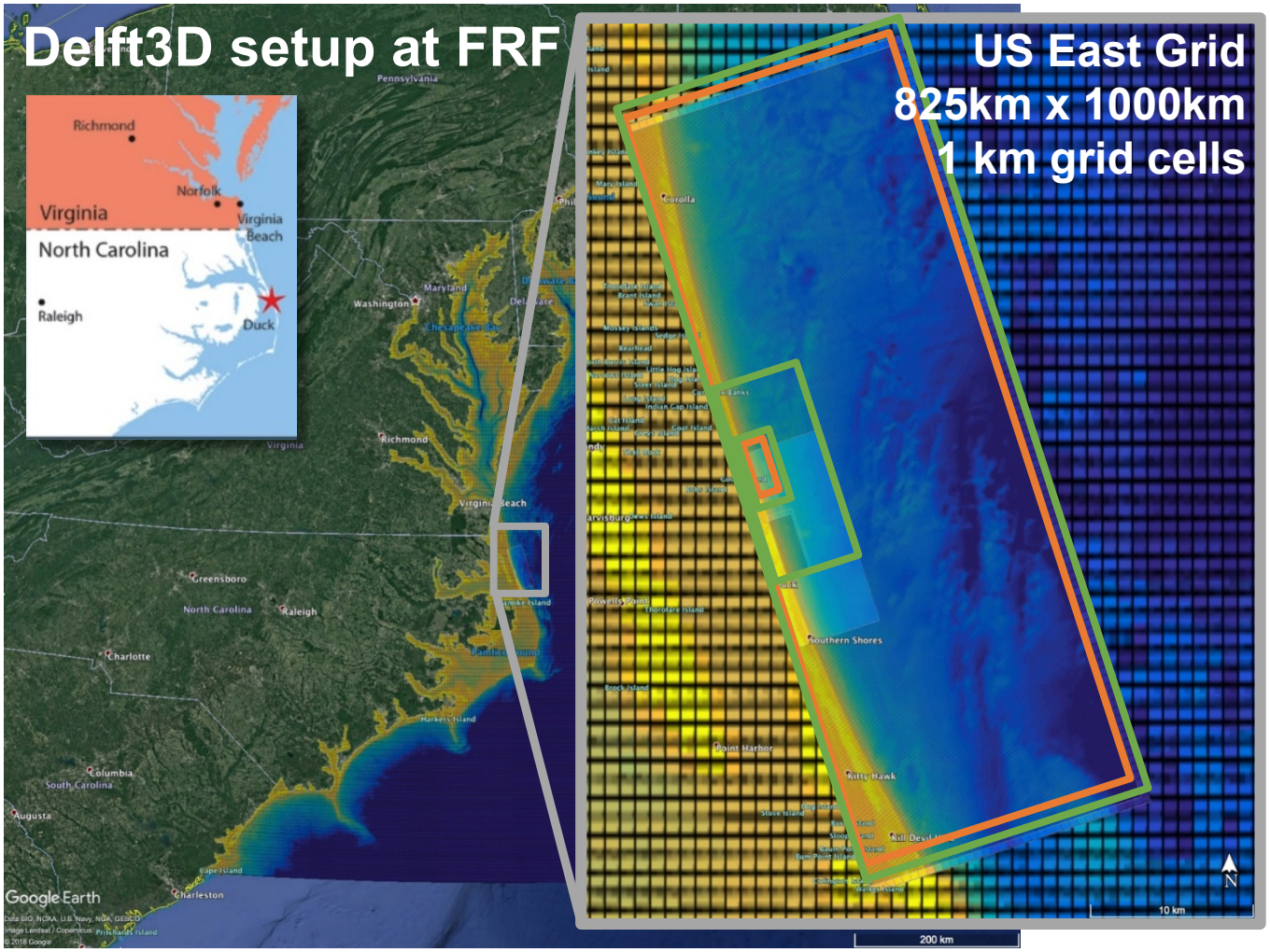
- MR-2733: Palmsten and Penko
- Nowcast/hindcasts of munitions mobility and burial
  - One-way coupled Delft3D with UnMES



Probability of total burial

Note: PEMS = probabilistic environmental modeling system

PEMS for Munitions Mobility



FLOW

outer
17.5 x 48km
100m cells

inner
2.5km x 4km
10m cells

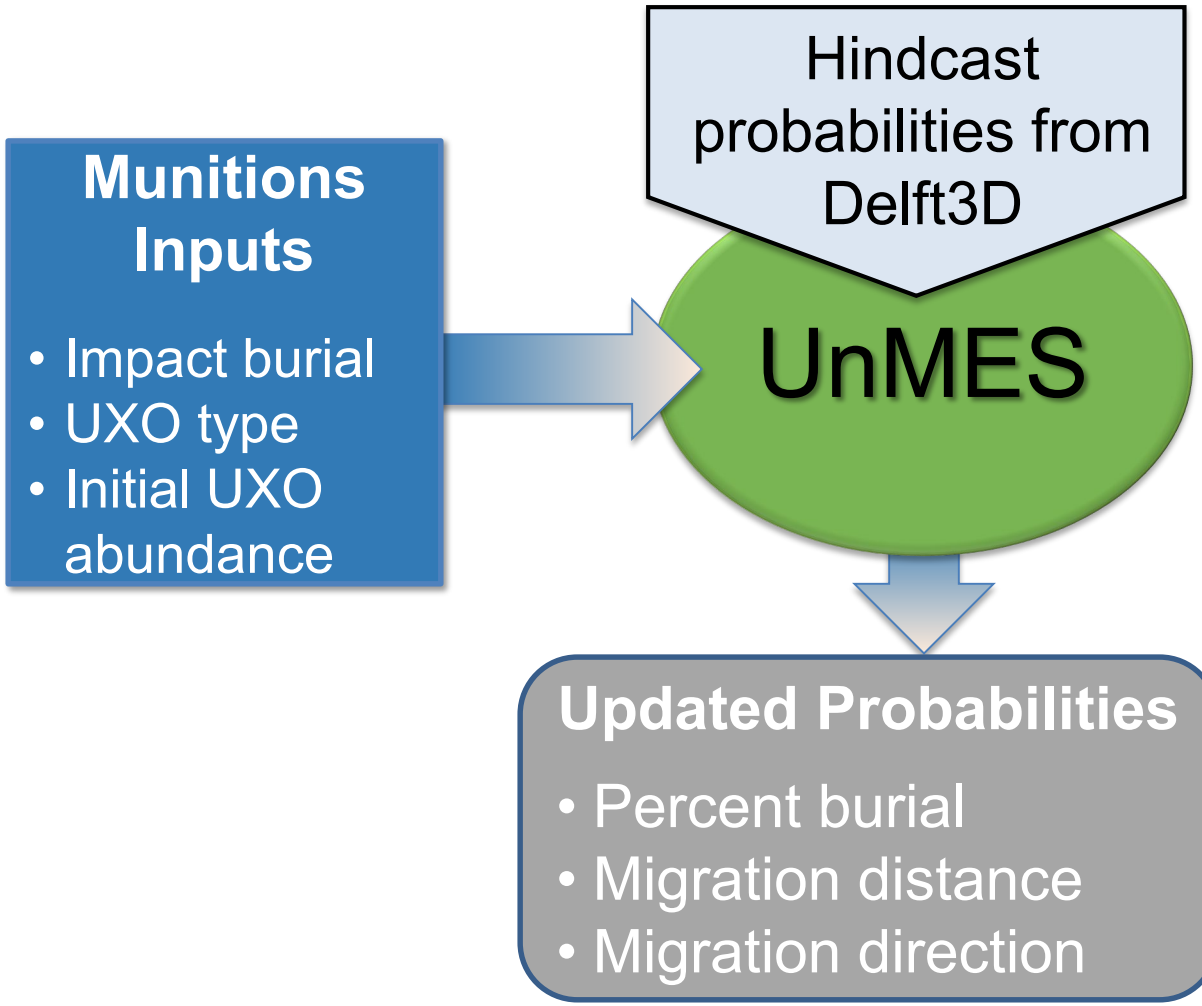
WAVE

outer
18km x 49km
500m cells

middle
5.5km x 13km
100m cells

inner
2km x 5km
50m cells

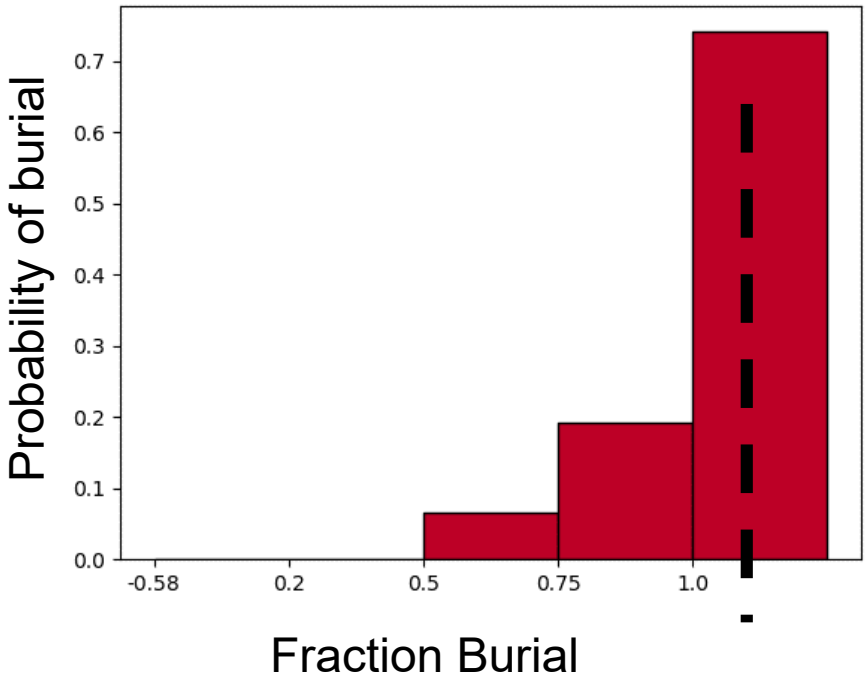
PEMS for Munitions Mobility

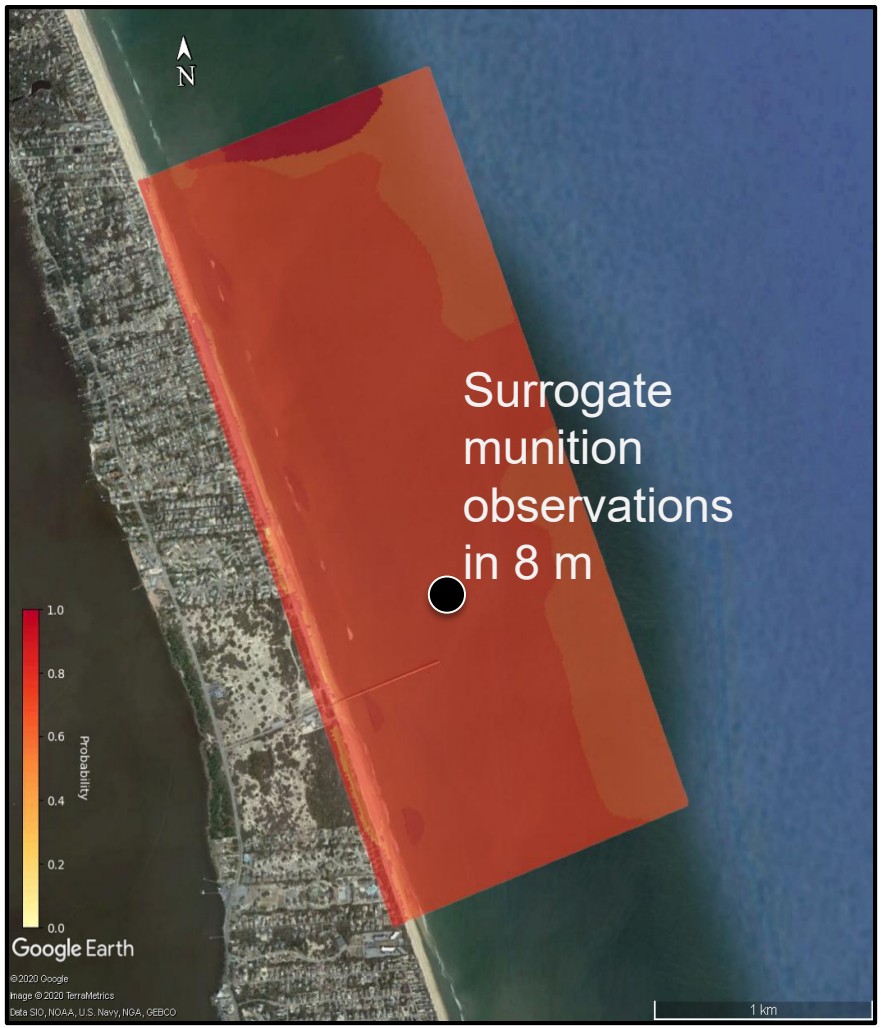


- **UnMES**
  - Underwater Munitions Expert System
- Developed by Rennie & Brandt
  - MR-2227
  - MR-2645
  - MR19-1126
- Machine Learning approach
- Trained with simple, physics-based formulations
- Predict probability distribution using Bayesian inference

PEMS for Munitions Mobility

Model-data comparison





CONOPS for Site Management

- Establish data collection for environmental parameters
- Perform surveys to detect and classify
- Customize prediction models
- Consult tactical decision aids
- Perform management action

Note: CONOPS = concept of operations

Summary

- Our understand of the physics of mobility and burial is maturing
- Wide range of technologies and models are developed and in-progress
- Demonstrations must have a temporal component
- No prior examples exist

Benefits to DoD

- Successful demonstrations will provide critical technologies for site management
- Solutions may be customized by site
- Cost savings of manage-in-place versus remediation

Acknowledgments

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For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Munitions-Underwater/MR19-1317

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Q&A Session 2

The next webinar is on October 8, 2020

Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available Fluorine-Free Foams (Part 1)

Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends